TEC-0081

An Assessment of the Horizontal Accuracy of Interim Terrain Data

Louis Fatale
Jeffrey Messmore
James Ackeret

April 1996

U.S. Army Corps of Engineers
Topographic Engineering Center
7701 Telegraph Road
Alexandria, Virginia 22315-3864

US Army Corps of Engineers
Topographic Engineering Center

T

E

C

Destroy this report when no longer needed.
Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The citation in this report of trade names of commercially available products does not constitute official endorsement or approval of the use of such products.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1996	Technical Report June 94- October 95

4. TITLE AND SUBTITLE
An Assessment of the Horizontal Accuracy of Interim Terrain Data

5. FUNDING NUMBERS
QE6113UE01

6. AUTHOR(S)
Louis Fatale
Jeffrey Messmore
James Ackeret

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Topographic Engineering Center
7701 Telegraph Road
Alexandria, VA 22315-3864

8. PERFORMING ORGANIZATION REPORT NUMBER
TEC-0081

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

19. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Within the U.S. Army and throughout the private sector, the accuracy of Digital Topographic Data (DTD) is often taken for granted. Users assume terrain data to be accurate merely because of its digital nature. This report describes a study that was undertaken to determine the horizontal accuracy of Interim Terrain Data (ITD), a 1:50,000-scale terrain analysis data base. ITD is composed of vector features and associated attributes representing land cover characteristics. It is produced by the Defense Mapping Agency (DMA) and provided to the U.S. Army to support near-term requirements on an interim basis until more standardized data is available. Because of its interim nature, ITD may be digitized from hard copy source ("carto-controlled") or produced solely from photography ("photo-controlled"). No definitive accuracy statement is provided with the data.
This study was initiated in 1994 with the collection of ground coordinates for over 400 selected ITD features. Each feature was located in the field using a Precise Lightweight Global Positioning System Receiver (PLGR) in the Precise Positioning Service (PPS) mode (10-meter horizontal accuracy). Universal Transverse Mercator (UTM) coordinates obtained from the PLGR were annotated for each feature.(continued)

14. SUBJECT TERMS		15. NUMBER OF PAGES
Accuracy	Terrain Data	32
Global Positioning System (GPS)		16. PRICE CODE
Geographic Information System (GIS)		

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

13. Continued.

The UTM coordinates for coincident features in the ITD digital files were subsequently extracted by GIS query to compare statistically the digital data with the field data, calculate the offsets, and determine the horizontal accuracy of the ITD. The potential accuracy differences between the carto- and photo-controlled ITD and the variability of natural vs. manmade features are also discussed.

CONTENTS

ILLUSTRATIONS

PREFACE

This study was performed during the period June 1994 to September 1995 under the supervision of Mr. Jeffrey Messmore, Chief, Special Studies Division, and Mr. Richard Herrmann, Director, Digital Concepts and Analysis Center.[1]

The authors would like to extend special appreciation to Mr. John Nedza, Geographic Information Lab, for the many hours of effort he provided during import of the raw Interim Terrain Data (ITD) data and subsequent conversion to Arc-Info coverages. His outstanding technical expertise greatly facilitated data analyses and played a critical role in the successful completion of this study.

The authors would also like to thank Mr. Bill Ryder, Special Studies Division, Digital Concepts and Analysis Center for his excellent terrain analysis support during the field collection; Professor Richard Scott, Rowan College, Glassboro, N.J. for advice and insight about the statistical processes used in the report; and Messrs. Robert Gormley and David Wu, Special Studies Division, Digital Concepts and Analysis Center for their work regarding research and compilation of the statistical analyses.

Mr. Walter E. Boge was Director, and Colonel Richard G. Johnson was Commander and Deputy Director of the Topographic Engineering Center at the time of publication of this report.

---

[1]When this report was printed, Mr. Regis J. Orsinger was the Director of the Digital Concepts and Analysis Center.

AN ASSESSMENT OF THE HORIZONTAL ACCURACY OF INTERIM TERRAIN DATA

INTRODUCTION AND BACKGROUND

Interim Terrain Data (ITD) was first produced by the Defense Mapping Agency (DMA) in 1987. Production of this data was initiated to fill the Army's urgent need for a digital terrain analysis product in support of emerging topographic and Command and Control (C2) systems. Earlier, in 1984, the Army had documented a digital topographic data (DTD) requirement that encompassed all Army's known and anticipated tactical DTD requirements. However, production against this requirement, described as Tactical Terrain Data (TTD), was not scheduled to commence until 1996. In order to get similar data to Army users, DMA initiated production of a product called ITD, the goal of which was to fill the data void until TTD production came on line. Due to the interim nature of this data set and the use of more than one production method, DMA does not state a formal horizontal accuracy measure for this product.

As the center of expertise for DTD within the Army, TEC's Digital Concepts and Analysis Center (DCAC) formulated this study to characterize the horizontal accuracy of ITD. Knowledge of horizontal accuracy is important to the Army as well as other DOD users because it affects what are appropriate uses of the product. For example, is ITD as accurate as the Topographic Line Map (TLM), which may be used for targeting purposes, or is it only as accurate as a city graphic, which is not an appropriate source for targeting? Fortunately, along with the need to know ITD's horizontal accuracy, technology for rapid position determination has become available in the form of Global Positioning Systems (GPS). This technology was applied to determine the horizontal positions of well-defined ITD features.

The ITD is produced through two production processes; one is a hard-copy digitizing process, and the other is a pure photogrammetric production process. In the hard-copy process, tactical terrain analysis data base (TTADB) Mylar overlays (which are geo-registered to the corresponding 1:50,000-scale TLM's) are digitized, resulting in a "carto-controlled" ITD product. In the photogrammetric production process, imagery from DMA's feature extraction (FE) workstation is used, resulting in a "photo-controlled" ITD product. It should be noted that ITD cells from both of these widely divergent production processes are currently

distributed and in broad use. Carto-controlled cells make up the bulk of currently available ITD (≈840 of 1340 cells). The ≈500 remaining cells are photo-controlled.

PURPOSE

The purpose of this study is to provide the Mapping Charting & Geodesy (MC&G) user community with information about the horizontal accuracy of ITD features. It is intended to give the user a level of confidence regarding ITD accuracy and to establish the utility of ITD for various applications. The study also identified accuracy differences between cartographic and photogrammetrically controlled ITD.

METHODOLOGY & FIELD COLLECTION PROCEDURE

To assist with DCAC's ITD accuracy investigations, DMA provided ITD hard-copy plots, digital data, and associated TLM's for 10 cells in the continental U.S. (CONUS). The use of the hard-copy plots (from digital ITD) instead of the TTADB ensured that features identified for analysis would be represented in the digital data. Each of these plots covered approximately a 15-by 15-minute area. There were four photo-controlled cells in the Alamagordo/Las Cruces, NM area as well as six carto-controlled cells, two in the Ft. Bragg, NC area, and four in the vicinity of Ft. Hood, TX.

Scientists at DCAC reviewed the hard-copy plots and identified appropriate features for field reconnaissance. Two factors weighed heavily in the selection of features. The first factor was the existence of a distinguishable point on the ground (e.g., a road intersection, bridge, dam, or fence line). The second factor was accessibility for measurement of its horizontal placement. No vertical accuracy criteria, such as feature height or height above mean sea level, were considered. The selected features were then annotated on the coinciding 1:50,000 TLM for field use. They comprised a representative sample from the Transportation (TRANS), Surface Drainage (SD), Obstacles (OBS), and Vegetation (VEG) overlays, since these contained point or line features that were more easily recognizable in the field (see Appendix A). Features in the Surface Configuration and Soils overlays were not used for this study. Although important for many applications, these features are not easily distinguishable on the ground and are difficult to measure accurately.

Depending on the density of the data, 14 to 73 features on each of the 10 cells in the study areas were chosen for analysis. The number and variety of features chosen were those deemed necessary to assure representative coverage throughout each cell. More than 400 features were subsequently visited in the field. Each site was located by using a Precise Lightweight Global Positioning System Receiver (PLGR) in the Precise Positioning Service (PPS) mode (≈10 meter horizontal accuracy). Universal Transverse Mercator (UTM) coordinates derived from the PLGR were annotated for each.

ANALYSIS

Data Preparation. The digital ITD files provided by DMA were partitioned on the provided media (9-track tape/6250 bpi) by individual sheet number and thematic layer(s). Related file header data was used to acquire descriptive information (metadata) about the individual data sets. The digital ITD files were archived in Standard Linear Format (SLF). Arc/Info (V. 7.0) was used to import the ITD-SLF files read from the tape. Upon import, the data was converted into Arc/Info coverages using the "SLFARC" command. Arc/Info's GIS functionalities enabled us to:

1. Identify and display selected features by thematic layer, feature type, and feature attributes.

2. Precisely extract UTM coordinates for selected features.

The Arc/Info coverages were geo-referenced in WGS-84 spherical geographic coordinates (LAT-LONG). Each coverage, maintained in single-coordinate precision (seven significant digits), was subsequently projected into a WGS-84 planar coordinate system (UTM) which was consistent with the GPS field collection coordinate system. Projection of coordinates from LAT-LONG to real-world UTM coordinates via the Arc/Info projection utilities was determined to be a virtually error-free process. Since both input and output coverages were stored in WGS-84 and required no additional datum transformations, the statistical significance of the root-mean-square (RMS) error was ≤ 0.010. [NOTE: A perfect projection with an RMS error of 0.000 is not possible with real-world data.] Customized graphical user interfaces were developed using Arc/Info's Arc Macro Language (AML) to extract digital ITD feature coordinates.

Digital ITD Coordinate Extraction. UTM coordinates for selected features were extracted in order to compare the field data to the digital data, calculate the offsets, and thereby determine the horizontal accuracy of ITD. Thematic coverages for

each cell in the study area were displayed with the features appearing as unsymbolized centerline data. Next, those ground features visited in the field were identified in the digital file. A coordinate pair was extracted and recorded alongside the coordinate pair of the coincident ground feature. Finally, a series of statistical analyses was performed on both sets of coordinates.

Statistical Analyses. Coordinates for the photo-controlled and the carto-controlled ITD features were stored in different files, which were further delineated by eastings and northings. These files were then grouped by specific feature types (e.g., "surface drainage features from photo-controlled data"). Standard statistical measures such as mean, standard deviation, 95 percent confidence interval of the mean and a t-statistic with an associated critical value were calculated for each data file. The mean and standard deviation determine the size of the error. The 95 percent confidence interval indicates the potential magnitude of that error in future measurements. The t-statistic determines whether there is a significant difference between two populations (e.g., between the field data and the photo/carto-controlled ITD). Further explanations of the individual statistics are found in Appendix B.

DISCUSSION/FINDINGS

During the field work, DCAC scientists visited 421 feature locations, collecting an easting and a northing at each for a total of 842 observations (combined photo-and carto-controlled data). A summary of statistics for this data is found in Table 1. Offsets ranged from a low of 0 meters (perfect correspondence between field & ITD coordinates) to a high of 339 meters. The average offset for all observations was 25 meters. When the GPS measurement error (Q value) of 10 meters is included, an average offset of 15 to 35 meters is established.

Table 1. Summary of ITD Feature Coordinate Offsets

# obs. (E&N)	*OFFSET (m) Low Mean High*	*Std. Dev. (m)*	*#/% offset 50m*	*#/% offset 100m*	*Q*
842	0 25 339	31	73/8.67	18/2.14	10

Q - measure of GPS error (circular) in meters
E&N - Eastings & Northings

Of the 842 total observations, 769 features (91.3 percent) were within 50 meters of their expected locations. This is within the expected accuracy of the 1:50,000 Class B TLM (50 meters circular @ 90 percent confidence), which is the only related product with a formal accuracy statement. Only 73 (8.7 percent) had field/ITD offsets above the 50 meter TLM baseline. Further examination revealed that 18 (2.1 percent) of the 73 had offsets more than 100 meters. As expected, 93 percent (68 of 73) of the offsets that were more than 50 meters occurred in cartographically controlled data. These errors were especially prevalent in the SD (e.g. dams, canals), OBS, and VEG coverages where 55 of the 73 offsets were observed. Potential rationales for the higher offsets in the carto-controlled SD, OBS, and VEG coverages (vs. photo-controlled ITD) lie in DMA's collection/symbolization techniques for this data as described below.

In carto-controlled ITD, horizontal positioning is keyed to a base map. Although many features are collected from imagery, they are still subject to a potential offset of 50 meters (map accuracy). Moreover, SD features, such as dams and canals, vegetation polygons, and especially obstacles are often displaced for symbolization purposes. Obstacles such as embankments, escarpments, ditches or road cuts may be substantially displaced to ensure the correct alignment of a stream or road bed. Moreover, it is often hard to determine the exact start or end point of an obstacle in the field.

Vegetation features are inherently characterized by their natural variability. Furthermore, ITD vegetation has a minimum areal size requirement resulting in the inclusion of many different vegetation types within a single polygon. The resulting boundaries can vary in these transition areas causing offsets.

The production procedure for delineation and depiction of dams and canal end/break points (above/below ground transition) is unlike that of other SD features in which positional accuracy is strictly upheld. Dam and canal lengths are often variable since they are roughly plotted to scale to provide a relative size. More emphasis is placed on the location/axis of these features rather than on their size/length.

Figure 1 depicts the data offset for an actual point bridge as observed on the Gatesville, Texas cell, map sheet 6446-1. The ITD bridge feature is approximately 25 meters from the road/stream crossing point where the field measurement took place. However, the actual position of the bridge may be as

close as 15 meters or as far as 35 meters from its intended location depending on the GPS error introduced in the field.

Table 2 illustrates various comparisons between the carto- and photo-controlled ITD at the thematic level. Carto feature offsets are acceptable, with some coverages performing better than others. For example, offsets for the carto transportation features averaged approximately 24 meters, while obstacles offsets approached 70 meters. The mean offset for the carto vegetation features (≈23m) was comparable to transportation but exhibited a much higher 95 percent confidence interval (≈22.5 vs. ≈4.5m). This indicates increased variability for the vegetation features and a potentially lower correlation with subsequent field observations.

Overall confidence intervals for the carto-controlled features ranged from ≈4m (transportation) to ≈53m (obstacles). The mean offset for the carto data is 28.8 meters. Conversely, the mean offsets of the photo-controlled features were very low across all thematic layers. They ranged from a low of 10-12 meters (vegetation, surface drainage, and transportation features) to a high of 21 meters (obstacles). The 95 percent confidence intervals are fairly consistent across features ranging from ≈6m (transportation) to ≈22 meters (obstacles). The mean offset for the photo data is 13.7 meters. This is directly attributable to the increased fidelity provided by a solely photogrammetric production technique.

It is recognized that statistics/comparisons for several feature groupings in Table 2 are based on small sample sizes (<30 observations). However, in each case the t-statistic exceeds the critical value, indicating that random error cannot explain the variance observed between the field data coordinates and those of ITD. Therefore, there is a significant difference between the populations at the 95 percent confidence level.

It should be noted that all of the ITD data used for this study was collected over CONUS areas with relatively reliable source materials. Assuming the availability of comparable sources, findings in this report should be extensible to any location. However, it is unknown to what extent, if any, foreign or other ancillary source materials may affect the results herein.

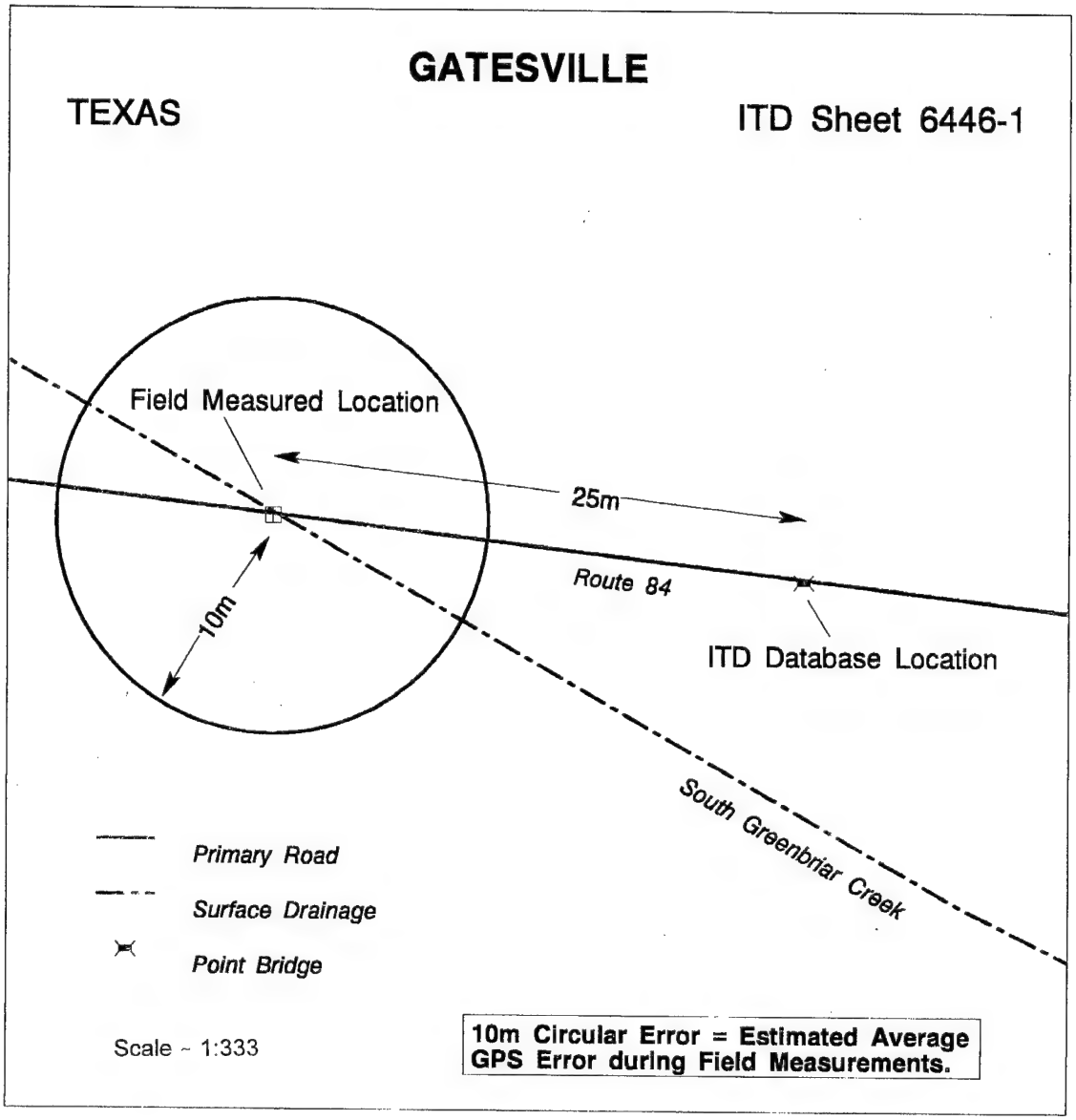

Figure 1. Data Point vs Field Point Offset

Table 2.--Carto/Photo ITD vs. Field Data Offsets by Feature & Associated Statistics

Photo-Controlled Data in meters

Measurement Type	*Average (Mean)*	*Std. Dev.*	*95% Confidence Int. Of Mean*	*T Stat.*	*Crit. Val.*	*Sample Size*
All features	**13.72**	19.49	10.98 - 16.47	9.8	1.65	196
Trans-portation features	**12.69**	17.29	9.69 - 15.69	8.37	1.66	130
Obstacle features	**21.31**	30.85	10.19 - 32.44	3.91	1.70	32
Surf. Drainage features	**11.00**	11.57	5.25 - 16.75	4.04	1.74	18
Vegetation features	**10.00**	9.56	4.91 - 15.09	4.19	1.75	16

Carto-Controlled Data in meters

Measurement Type	*Average (Mean)*	*Std. Dev.*	*95% Confidence Int. Of Mean*	*T. Stat.*	*Crit. Val.*	*Sample Size*
All features	**28.76**	32.25	26.27 - 31.25	22.67	1.65	646
Trans-portation features	**24.43**	24.97	22.20 - 26.65	21.61	1.65	488
Obstacle features	**69.68**	75.57	43.30 - 96.05	5.38	1.69	34
Surf. Drainage features	**37.04**	30.05	31.14 - 42.94	12.45	1.66	102
Vegetation features	**23.27**	25.42	12.00 - 34.54	4.29	1.72	22

CONCLUSIONS

1. The offset of well-defined ITD features taken as a whole was approximately 25 meters. Approximately 90 percent of these features were within 50 meters of their expected locations. This meets the accuracy specification of 50 meters for a Class B, 1:50,000-scale TLM, a traditional source for targeting information.

2. Overall, carto-controlled ITD feature offsets (29 meters) were higher than photo-controlled ITD feature offsets (14 meters). Our expectations were that the photo-controlled ITD would perform very well, as it did; however, performance of the carto-controlled ITD was also suprisingly good.

3. The positional accuracy of ITD features was determined to be compatible with the positional accuracy of hand-held precise GPS equipment currently used in the field. This accuracy compatibility will lessen the chance for confusion and correlation problems, such as could occur when features are located close to one another on the ground and GPS-derived locations do not match data base locations. This problem may be more of a concern with lower accuracy data sets, such as VMap Level 1 (1:250,000 scale) and DCW (1:1,000,000 scale).

LIST OF ACRONYMS

AML	Arc Macro Language
C^2	Command and Control
CONUS	Continental United States
DCAC	Digital Concepts and Analysis Center
DCW	Digital Chart of the World
DMA	Defense Mapping Agency
DOD	Department of Defense
E & N	Easting and Northing
FE	Feature Extraction
GPS	Global Positioning System
ITD	Interim Terrain Data
LAT/LONG	Latitude/Longitude
MC&G	Mapping, Charting, and Geodesy
OBS	Obstacles
PLGR	Precise Lightweight Global Positioning System Receiver
PPS	Precise Positioning Service
RMS	Root-Mean-Square
SD	Surface Drainage
TEC	Topographic Engineering Center
TLM	Topographic Line Map
TRANS	Transportation
TTADB	Tactical Terrain Analysis Data Base
TTD	Tactical Terrain Data
UTM	Universal Transverse Mercator
VEG	Vegetation
VMap	Vector Smart Map
WGS 84	World Geodetic System 1984

APPENDIX A. LIST OF FEATURES USED FOR ITD ACCURACY ANALYSIS

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
6446-3	Ft Hood, TX	Enbankment	612236E 3439270N	612211E 3439299	Carto
		Dam	601152E 3440698N	601138E 3440711N	
		Canal	615675E 3444048N	615713E 3444142N	
		Canal	618715E 3445428N	618703E 3445472	
		Dam	614521E 3447867N	614502E 3447927N	
		Dam	600534E 3451879N	600551E 3451932N	
		Dam	603833E 3457106N	603806E 3457133N	
		Bridge	612461E 3443791N	612473E 3443782N	
		Bridge	602949E 3441761N	602916E 3441715N	
		Bridge	596393E 3438843N	596349E 3438820N	
		Intersection	598382E 3437559N	598416E 3437602N	
		Intersection	603169E 3434389N	603139E 3434362N	
		Bridge	603771E 3430498N	603780E 3430492N	
		Bridge	606084E 3430848N	606078E 3430860N	
		Intersection	608351E 3435176N	608352E 3435157N	
		Intersection	610708E 3441426N	610677E 3441406N	
		Bridge	611441E 3441161N	611453E 3441160N	
		Bridge	614365E 3433882N	614392E 3433891N	
		Intersection	618432E 3438905N	618392E 3438916N	
		Intersection	617649E 3445778N	617663E 3445792N	
		Intersection	610652E 3445582N	610677E 3445620N	
		Bridge	612829E 3447389N	612871E 3447448N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
6646-3	Ft Hood, TX	Intersection	610243E 3452197N	610210E 3452218N	Carto
		Intersection	610278E 3448437N	610266E 3448446N	
		Intersection	609292E 3444767N	609296E 3444794N	
		Bridge	606925E 3446290N	606910E 3446331N	
		Bridge	606958E 3445267N	606944E 3445289N	
		RR Crossing	604570E 3447927N	604552E 3447966N	
		Bridge	601837E 3454347N	601825E 3454364N	
		RR Crossing	600230E 3457508N	600251E 3457491N	
		Intersection	599383E 3456696N	599335E 3456773N	
		Intersection	596695E 3454347N	596680E 3454364N	
		Bridge	601679E 3451879N	601688E 3457491N	
		Intersection	603913E 3456696N	603896E 3456773N	
		Bridge	603648E 3455382N	603632E 3455381N	
		Veg	614601E 3443070N	614492E 3443068N	
		Veg	614659E 3443335N	614672E 3443378N	
		Veg	618071E 3438827N	618133E 3438838N	
		Veg	618014E 3438659N	617999E 3438658N	
5154-3	S. Pines, NC	Hedgerow	647612E 3883884N	647589E 3883900N	Carto
		Hedgerow	654834E 3875056N	654598E 3875104N	
		Escarpment	653902E 3901450N	653909E 3901480N	
		Escarpment	653318E 3901582N	653398E 3901468N	
		Hedgerow	639646E 3888422N	639651E 3888474N	
		Dam	658618E 3895060N	658673E 3894973N	
		Dam	658491E 3895058N	658440E 3894969N	
		Dam	647793E 3885606N	647825E 3885555N	
		Dam	638742E 3885007N	638710E 3884974N	
		Dam	638067E 3876549N	638022E 3876521N	
		Dam	637986E 3876802N	637946E 3876738N	
		Dam	655077E 3895868N	655096E 3895795N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
5154-3	S. Pines, NC	Dam	644347E 3897558N	644297E 3897527N	Carto
		Dam	641612E 3899349N	641590E 3899308N	
		Dam	645541E 3890682N	645530E 3890644N	
		Culvert	655308E 3892756N	655308E 3892730N	
		Bridge	653375E 3891897N	653381E 3891897N	
		Intersection	650815E 3891228N	650811E 3891202N	
		Intersection	647444E 3890524N	647475E 3890497N	
		Intersection	648608E 3884290N	648634E 3884284N	
		Culvert	646803E 3882437N	646825E 3882409N	
		Intersection	649561E 3876123N	649581E 3876123N	
		Culvert	651602E 3875322N	651598E 3875352N	
		Intersection	654536E 3875182N	654547E 3875148N	
		Bridge	646894E 3875818N	646886E 3875800N	
		Bridge	644370E 3879661N	644388E 3879625N	
		Bridge	640181E 3883193N	640164E 3883166N	
		Bridge	639308E 3883724N	639293E 3883706N	
		RR Bridge	637964E 3879795N	637950E 3879776N	
		Intersection	637041E 3880440N	637045E 3880401N	
		Intersection	643237E 3882771N	643240E 3882740N	
		Bridge	642069E 3876720N	642059E 3876650N	
		RR Crossing	640897E 3875525N	640904E 3875545N	
		RR Crossing	639850E 3875450N	639821E 3875448N	
		Bridge	638787E 3877334N	638764E 3877365N	
		RR Crossing	637723E 3877627N	637743E 3877592N	
		RR Crossing	637251E 3879071N	637260E 3879021N	
		RR Crossing	637106E 3879120N	637139E 3879108N	
		RR Crossing	637722E 3877315N	637762E 3877290N	
		Intersection	651349E 3882662N	651380E 3882656N	
		RR Crossing	657343E 3883748N	657359E 3883713N	
		Intersection	657709E 3880950N	657703E 3880941N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
5154-3	S. Pines, NC	Bridge	649989E 3891562N	649982E 3891533N	Carto
		RR Crossing	646665E 3893685N	646684E 3893630N	
		RR Bridge	645701E 3892795N	645722E 3892759N	
		Intersection	658668E 3898187N	658662E 3898177N	
		Culvert	657110E 3899111N	657113E 3899107N	
		Intersection	654251E 3900762N	654265E 3900776N	
		Bridge	654991E 3901200N	655002E 3901185N	
		Intersection	648893E 3901028N	648890E 3901013N	
		Bridge	649381E 3898330N	649334E 3898362N	
		Intersection	649467E 3896655N	649481E 3896623N	
		Bridge	646070E 3898360N	646048E 3898381N	
		Intersection	641145E 3896577N	641161E 3896535N	
		Intersection	640958E 3899258N	640955E 3899221N	
		Bridge	641272E 3900515N	641253E 3900472N	
		Bridge	637627E 3899910N	637601E 3899853N	
		Culvert	638452E 3898448N	638471E 3898393N	
		Intersection	638789E 3895800N	638785E 3895780N	
		Bridge	643040E 3893622N	643026E 3893651N	
		Bridge	637160E 3891736N	637101E 3891732N	
		Intersection	639767E 3890356N	639766E 3890313N	
		Culvert	641248E 3888409N	641229E 3888388N	
		RR Bridge	643012E 3888869N	643006E 3888860N	
		RR Bridge	643626E 3889215N	643592E 3889191N	
		Veg	643250E 3896449N	643227E 3896392N	
6446-1	Gtsvlle, TX	Embankment	636020E 3474037N	635832E 3474032N	Carto
		Embankment	623743E 3469601N	623750E 3469537N	
		Embankment	623335E 3470156N	623336E 3470120N	
		Dam	620569E 3483618N	620544E 3483606N	
		Dam	632108E 3480786N	632133E 3480787N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
6446-1	Gtsvlle, TX	Dam	621354E 3475762N	621382E 3475745N	Carto
		Intersection	619358E 3478498N	619373E 3478474N	
		Intersection	620154E 3483541N	620186E 3483519N	
		Bridge	619546E 3484672N	619525E 3484708N	
		Bridge	625009E 3485357N	625002E 3485309N	
		Culvert	630407E 3482051N	630387E 3482057N	
		Bridge	627952E 3477804N	627927E 3477791N	
		Bridge	633273E 3477574N	633281E 3477550N	
		Bridge	637903E 3478469N	637918E 3478474N	
		Culvert	639389E 3481077N	639421E 3481101N	
		Intersection	639745E 3482187N	639758E 3482189N	
		Bridge	637139E 3485114N	637128E 3485125N	
		Intersection	642206E 3484883N	642217E 3484848N	
		Bridge	642108E 3485294N	642124E 3485254N	
		RR Crossing	641872E 3476955N	641891E 3476904N	
		Intersection	640600E 3472100N	640617E 3472072N	
		Bridge	639334E 3472937N	639379E 3472957N	
		Bridge	636034E 3472727N	636102E 3472772N	
		Bridge	633134E 3474033N	633145E 3474058N	
		Bridge	633344E 3474034N	633357E 3474054N	
		Intersection	631370E 3473751N	631425E 3473750N	
		Bridge	627608E 3474296N	627610E 3474310N	
		RR Crossing	624019E 3475633N	624032E 3475665N	
		Bridge	623346E 3473061N	623365E 3473055N	
		Bridge	623469E 3472803N	623491E 3472751N	
		Intersection	623801E 3472078N	623848E 3472044N	
		Bridge	620781E 3470228N	620780E 3470200N	
		RR Crossing	625162E 3470791N	625151E 3470705N	
		RR Crossing	626392E 3470036N	626363E 3470048N	
		RR Crossing	626091E 3470600N	626037E 3470645N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
6446-1	Gtsvlle, TX	RR Crossing	627009E 3471319N	627054E 3471307N	Carto
		RR Crossing	626559E 3472283N	626572E 3472256N	
		Intersection	628417E 3466272N	628471E 3466246N	
		Bridge	629100E 3467627N	629136E 3467650N	
		Intersection	629588E 3469356N	629617E 3469327N	
		RR Crossing	629864E 3464385N	629840E 3464390N	
		Intersection	631809E 3463629N	631833E 3463621N	
		Bridge	633558E 3460735N	633508E 3460726N	
		Intersection	635882E 3458878N	635901E 3458832N	
		Intersection	641192E 3460735N	641155E 3460789N	
		Bridge	632954E 3469163N	632966E 3469164N	
		Intersection	635168E 3468303N	635197E 3468295N	
		Bridge	639842E 3469409N	639826E 3469390N	
		Bridge	639694E 3469618N	639680E 3469578N	
		Veg	620448E 3478827N	620457E 3478835N	
6446-2	Kileen, TX	Fence	621510E 3445934N	621606E 3446019N	Carto
		Dam	640448E 3433611N	640382E 3433555N	
		Dam	640033E 3432615N	639989E 3432595N	
		Dam	623227E 3437054N	623202E 3437098N	
		Dam	632025E 3448194N	631960E 3448164N	
		Dam	636824E 3445119N	636817E 3445130N	
		Dam	634618E 3438880N	634648E 3438823N	
		Dam	633533E 3442258N	633558E 3442222N	
		Dam	626060E 3439811N	626031E 3439792N	
		Dam	625992E 3439862N	625963E 3439834N	
		Dam	625924E 3439894N	625875E 3439889N	
		Canal	621810E 3444471N	621691E 3444570N	
		Dam	623546E 3445851N	623579E 3445841N	
		Intersection	640647E 3434695N	640614E 3434707N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
6446-2	Kileen, TX	Intersection	633937E 3436873N	633905E 3436973N	Carto
		Intersection	629191E 3436217N	629161E 3436221N	
		Bridge	628739E 3431566N	628721E 3431590N	
		Bridge	629368E 3431225N	629394E 3431229N	
		Bridge	627409E 3434251N	627354E 3434228N	
		Intersection	624917E 3433549N	624898E 3433540N	
		Intersection	620823E 3433556N	620807E 3433539N	
		Intersection	619490E 3436219N	619474E 3436224N	
		Intersection	622900E 3447695N	622930E 3447690N	
		Intersection	631809E 3448350N	631786E 3448355N	
		Intersection	630910E 3450406N	630895E 3450380N	
		Culvert	629653E 3452862N	629598E 3452741N	
		Bridge	629913E 3453300N	629838E 3453181N	
		Bridge	632545E 3447583N	632548E 3447578N	
		Intersection	641494E 3441626N	641497E 3441617N	
		Bridge	640503E 3440679N	640474E 3440665N	
		RR Crossing	639165E 3439701N	639176E 3439680N	
		Bridge	635613E 3437928N	635664E 3437906N	
		Bridge	635528E 3437969N	635387E 3438032N	
		RR Bridge	633503E 3438800N	633458E 3438828N	
		Bridge	634536E 3440113N	634510E 3440074N	
		Bridge	625171E 3441837N	625192E 3441821N	
		Bridge	625085E 3441773N	625084E 3441761N	
		Bridge	623935E 3442572N	623894E 3442573N	
		Bridge	622830E 3443032N	622848E 3443087N	
		RR Crossing	621484E 3443444N	621384E 3443498N	
		RR Bridge	619344E 3443784N	619345E 3443804N	
		Bridge	639590E 3456637N	639593E 3456613N	
		RR Crossing	641437E 3456560N	641457E 3456642N	
		Bridge	642220E 3456627N	642236E 3456551N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
6446-2	Kileen, TX	Culvert	642376E 3456891N	642360E 3456854N	Carto
		Veg	623892E 3436271N	623904E 3436241N	
		Veg	624085E 3436352N	624080E 3436333N	
6446-4	Purmela, TX	Escarpment	614325E 3459098N	614357E 3459074N	Carto
		Dam	611342E 3462480N	611279E 3462665N	
		Dam	598636E 3470160N	598624E 3470168N	
		Dam	618222E 3472729N	618225E 3472777N	
		Dam	597188E 3482222N	597165E 3482238N	
		RR Crossing	611766E 3460071N	611800E 3460079N	
		Intersection	612071E 3461831N	612098E 3461799N	
		Intersection	603726E 3459003N	603739E 3459025N	
		Intersection	597701E 3461129N	597673E 3461123N	
		Bridge	606178E 3461767N	606141E 3461710N	
		Bridge	606239E 3461871N	606216E 3461846N	
		Intersection	605810E 3461088N	605780E 3461103N	
		Intersection	601294E 3467052N	601295E 3467060N	
		Bridge	595896E 3467660N	595905E 3467660N	
		Bridge	602910E 3471970N	602964E 3471972N	
		Bridge	602994E 3471984N	603073E 3471992N	
		Bridge	610876E 3474273N	610892E 3474292N	
		Intersection	613390E 3474034N	613364E 3474044N	
		Intersection	608913E 3468643N	608904E 3468636N	
		Culvert	616790E 3469255N	616829E 3469245N	
		Intersection	615598E 3468910N	615618E 3468933N	
		Bridge	618213E 3466087N	618238E 3466071N	
		Intersection	617535E 3462579N	617561E 3462561N	
		RR Crossing	614417E 3476328N	614400E 3476383N	
		Bridge	615053E 3478377N	615049E 3478380N	
		Intersection	611844E 3478834N	611749E 3478787N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
6446-4	Purmela, TX	Culvert	608495E 3478687N	608500E 3478675N	Carto
		Bridge	601335E 3475281N	601358E 3475301N	
		Intersection	604494E 3480033N	604445E 3480036N	
		Culvert	603191E 3480475N	603199E 3480468N	
		Culvert	603640E 3480307N	603636E 3480301N	
		Bridge	596928E 3479897N	596888E 3479909N	
		Intersection	598572E 3483744N	598555E 3483754N	
		Bridge	598511E 3483850N	598528E 3483843N	
		Bridge	605711E 3484555N	605677E 3484559N	
		Bridge	608088E 3485626N	608040E 3485561N	
		Intersection	609356E 3483656N	609317E 3483660N	
		Bridge	614235E 3483123N	614253E 3483110N	
		RR Crossing	613555E 3483499N	613511E 3483533N	
		Intersection	617119E 3478496N	617115E 3478477N	
		Bridge	617687E 3478481N	617759E 3478487N	
		Bridge	617983E 3478483N	618053E 3478481N	
		Veg	602766E 3476602N	602784E 3476574N	
		Veg	602524E 3475830N	602520E 3475851N	
5254-3	Fayetvlle, NC	Hedgerow	698560E 3902238N	698527E 3902260N	Carto
		Hedgerow	698828E 3902418N	698767E 3902433N	
		Embankment	688976E 3887458N	689046E 3887404N	
		Hedgerow	690583E 3882709N	690505E 3882788N	
		Hedgerow	695243E 3881569N	695301E 3881688N	
		Escarpment	701409E 3885266N	701070E 3885043N	
		Dam	687376E 3890552N	687369E 3890577N	
		Dam	687378E 3890408N	687361E 3890435N	
		Dam	685796E 3901018N	685824E 3901008N	
		Dam	687228E 3901251N	687217E 3901230N	
		Dam	688213E 3902275N	688235E 3902272N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
5254-3	Fayetvlle, NC	Dam	691884E 3899280N	691885E 3899222N	Carto
		Dam	692141E 3899452N	692149E 3899395N	
		Dam	698946E 3900134N	698907E 3900074N	
		Dam	698892E 3900002N	698876E 3899957N	
		Canal	686771E 3881603N	686641E 3881644N	
		Dam	684201E 3878045N	684195E 3878042N	
		Dam	684091E 3878069N	684101E 3878080N	
		Dam	684195E 3875250N	684193E 3875266N	
		Dam	689552E 3881090N	689512E 3881160N	
		RR Crossing	684338E 3888530N	684342E 3888511N	
		RR Bridge	686700E 3890292N	686703E 3890319N	
		RR Crossing	687316E 3889569N	687653E 3889590N	
		RR Crossing	688731E 3889699N	688709E 3889692N	
		Intersection	683262E 3889916N	683238E 3889901N	
		Intersection	684994E 3891858N	684962E 3891890N	
		RR Crossing	684729E 3892798N	684704E 3892772N	
		Intersection	684620E 3893506N	684601E 3893596N	
		Bridge	683239E 3896469N	683215E 3896468N	
		Bridge	683398E 3896352N	683384E 3896312N	
		Bridge	686364E 3897405N	686401E 3897505N	
		Bridge	687778E 3899046N	687773E 3899042N	
		Intersection	684902E 3901451N	684890E 3901481N	
		Intersection	687929E 3900666N	687918E 3900664N	
		Intersection	692663E 3901641N	692689E 3901635N	
		Bridge	693068E 3900799N	693090E 3900774N	
		Intersection	689555E 3894894N	689558E 3894873N	
		Intersection	695794E 3897946N	695811E 3897963N	
		Intersection	699284E 3900244N	699270E 3900248N	
		RR Crossing	702077E 3897360N	702057E 3897339N	
		Intersection	696830E 3895386N	696836E 3895374N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
5254-3	Fayetvlle, NC	RR Crossing	694982E 3893758N	694960E 3893761N	Carto
		Intersection	696860E 3892900N	696859E 3892911N	
		RR Bridge	695196E 3891817N	695214E 3891849N	
		Intersection	691516E 3886491N	691536E 3886483N	
		Bridge	689225E 3884899N	689228E 3884890N	
		Intersection	685145E 3885782N	685154E 3885806N	
		Intersection	683336E 3883675N	683345E 3883685N	
		Bridge	684484E 3883110N	684491E 3883103N	
		Intersection	684609E 3879853N	684584E 3879842N	
		Bridge	684470E 3875250N	684435E 3875266N	
		Intersection	685474E 3875462N	685518E 3875502N	
		RR Bridge	689469E 3876917N	689511E 3876932N	
		Intersection	688309E 3879937N	688355E 3879907N	
		Intersection	688481E 3882056N	688491E 3882070N	
		Intersection	693415E 3882420N	693417E 3882320N	
		Bridge	695736E 3881689N	695661E 3881649N	
		Bridge	695442E 3881606N	695513E 3881603N	
		Bridge	695343E 3880735N	695359E 3880736N	
		Bridge	695514E 3880658N	695543E 3880654N	
		Bridge	698873E 3876023N	698861E 3876071N	
		Bridge	701832E 3877111N	701843E 3877130N	
		Intersection	703153E 3875945N	703142E 3875956N	
		Intersection	703734E 3883561N	703697E 3883595N	
		Intersection	704652E 3889022N	704593E 3889016N	
		RR Crossing	700507E 3888062N	700524E 3888038N	
		Intersection	702567E 3891612N	702564E 3891625N	
		Bridge	704579E 3894461N	704576E 3894457N	
		Intersection	696703E 3888154N	696694E 3888157N	
		RR Crossing	696189E 3884635N	696203E 3884614N	
		Veg	687869E 3889309N	687881E 3889315N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
4649-3	Sn Diego Mt, NM	Embankment	319694E 3602811N	319669E 3602917N	Photo
		Embankment	319902E 3602289N	319986E 3602169N	
		Dam	312677E 3601301N	312693E 3601267N	
		Bridge	318908E 3597557N	318897E 3597589N	
		Bridge	313092E 3601316N	313098E 3601324N	
		Bridge	312608E 3602266N	312608E 3602260N	
		RR Bridge	312551E 3610308N	312559E 3610307N	
		Intersection	314258E 3618851N	314234E 3618851N	
		Intersection	315469E 3618890N	315426E 3618900N	
		Intersection	318688E 3618948N	318660E 3618974N	
		Intersection	316283E 3611107N	316278E 3611093N	
		Intersection	318512E 3606332N	318488E 3606327N	
		Intersection	320260E 3602535N	320250E 3602550N	
		Intersection	320868E 3601240N	320871E 3601236N	
		Bridge	320620E 3600195N	320595E 3600185N	
		Veg	317143E 3605719N	317127E 3605715N	
4648-3	Afton, NM	Canal	330578E 3567167N	330575E 3567161N	Photo
		Intersection	334762E 3563269N	334753E 3563267N	
		Intersection	334604E 3563591N	334599E 3563595N	
		Bridge	334246E 3563617N	334242E 3563605N	
		RR Crossing	333868E 3561458N	333862E 3561455N	
		Bridge	334169E 3564683N	334167E 3564678N	
		Bridge	334250E 3565450N	334250E 3565450N	
		Bridge	334260E 3565560N	334261E 3565569N	
		Bridge	334302E 3566048N	334301E 3566053N	
		Intersection	334400E 3567184N	334388E 3567199N	
		Intersection	333706E 3568456N	333713E 3568454N	
4648-1	Organ Peak, NM	Fence	348364E 3595868N	348391E 3595854N	Photo
		Embankment	336249E 3576812N	336255E 3576807N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
4648-1	Organ Peak, NM	Embankment	336390E 3576960N	336407E 3576951N	Photo
		Embankment	335877E 3576752N	335894E 3576736N	
		Embankment	337332E 3574594N	337333E 3574599N	
		Canal	338617E 3595980N	338621E 3595963N	
		Canal	338639E 3596409N	338629E 3596409N	
		Dam	338854E 3577645N	338854E 3577660N	
		Dam	342513E 3579290N	342515E 3579298N	
		Dam	339300E 3579062N	339287E 3579063N	
		Dam	339865E 3582598N	339872E 3582595N	
		Culvert	357102E 3589906N	357110E 3589890N	
		Bridge	355954E 3589884N	355968E 3589868N	
		Bridge	354952E 3589866N	354975E 3589849N	
		Bridge	350363E 3588951N	350376E 3588962N	
		Intersection	348340E 3588354N	348325E 3588366N	
		Culvert	348322E 3594259N	348338E 3594252N	
		Intersection	341697E 3585625N	341703E 3585601N	
		Intersection	337347E 3583917N	337310E 3583881N	
		Intersection	337717E 3586795N	337693E 3586772N	
		Bridge	337324E 3590839N	337327E 3590825N	
		Bridge	337042E 3593026N	337034E 3593054N	
		Bridge	336905E 3593917N	336922E 3593917N	
		Intersection	336721E 3595366N	336724E 3595367N	
		Bridge	335389E 3576897N	335416E 3576905N	
		Intersection	338398E 3577631N	338408E 3577616N	
		Intersection	341626E 3578993N	341626E 3578987N	
		Intersection	336695E 3573853N	336700E 3573836N	
		Intersection	343152E 3575268N	343276E 3575286N	
		Intersection	346998E 3577994N	347040E 3577887N	
		RR Crossing	350275E 3578157N	350265E 3578121N	
		Veg	342194E 3592762N	342202E 3592755N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
4648-1	Organ Peak, NM	Veg	342586E 3592754N	342600E 3592752N	Photo
		Veg	340689E 3584703N	340689E 3584715N	
		Veg	340522E 3584706N	340487E 3584716N	
		Veg	340494E 3584325N	340484E 3584311N	
		Veg	340686E 3584316N	340681E 3584308N	
		Veg	335375E 3569766N	335373E 3569762N	
4749-1	Hollomn AFB, NM	Embankment	394613E 3634347N	394605E 3634334N	Photo
		Embankment	394745E 3633743N	394737E 3633746N	
		Escarpment	394647E 3639836N	394648E 3639797N	
		Fence	397025E 3638228N	397033E 3638228N	
		Fence	397514E 3638265N	397516E 3638267N	
		Fence	398544E 3637871N	398552E 3637868N	
		Fence	398544E 3638334N	398562E 3638324N	
		Escarpment	397616E 3640263N	397603E 3640247N	
		Escarpment	401876E 3644321N	401945E 3644316N	
		Canal	397784E 3633706N	397827 3633713N	
		Bridge	400204E 3633233N	400208E 3633205N	
		Intersection	399103E 3634194N	399088E 3634186N	
		Bridge	398656E 3632375N	398657E 3632373N	
		Intersection	398680E 3632334N	398684E 3632334N	
		Intersection	393443E 3629277N	393443E 3629255N	
		Intersection	390214E 3627364N	390209E 3627345N	
		Intersection	387538E 3628968N	387540E 3628960N	
		Intersection	405318E 3635535N	405350E 3635571N	
		Bridge	397268E 3632966N	397270E 3632961N	
		RR Crossing	393571E 3634483N	393577E 3634476N	
		Intersection	395407E 3637829N	395409E 3637828N	
		Bridge	392789E 3640877N	392797E 3640877N	
		Bridge	392581E 3644460N	392575E 3644457N	

Sheet	Sheet Name/St.	Feature	UTM Coordinates Field	UTM Coordinates Digital File	Control Source
4749-1	Hollomn, NM	Bridge	392524E 3645393N	392522E 3645393N	Photo
		Bridge	392365E 3648006N	392367E 3648006N	
		RR Crossing	392435E 3639098N	392441E 3639104N	
		Intersection	393792E 3642802N	393792E 3642818N	
		Intersection	393802E 3645964N	393804E 3645919N	
		RR Crossing	398914E 3634658N	398943E 3634722N	
		RR Crossing	400107E 3635825N	400111E 3635831N	
		Intersection	397853E 3641726N	397858E 3641736N	
		RR Bridge	406519E 3651646N	406516E 3651642N	
		Intersection	404539E 3646317N	404538E 3646318N	

APPENDIX B. STATISTICAL EXPLANATIONS

Sample Size/Mean - For this study, sample size is the number of northings and eastings in a given data grouping. A single sample represents the difference in meters between the field coordinates and the photo/carto-controlled ITD coordinates at a specific point. Mean was determined by taking the sum of all errors and dividing by the sample size.

Standard Deviation - A measure indicating the extent to which the data values are distributed about the mean. In a normal distribution, 68 percent of all values should fall within one standard deviation of the mean. The standard deviation is proportional to the sum of the difference between each value and the mean squared.

95 Percent Confidence Interval - Indicates, with 95 percent certainty, the range in which the mean is situated.

T-statistic/Critical Value - This statistic is dependent upon sample size and determines the probability that the actual variance observed can be solely explained by random error. The critical value is the threshold that the T-statistic must exceed, at a given confidence level and sample size, to ensure rejection of the null hypothesis (i.e., for this study, that there is no difference between the field data coordinates and those of the ITD data). Therefore, for a given sample size of >30 observations, a t-statistic of ≈1.65 represents a 0.05 probability that the measured error is solely random. A t-statistic of 2.58 represents a 0.005 probability of random error and a t-statistic of 6.90 represents a $5.48 \text{ by } 10^{-10}$ probability. For smaller sample sizes (15 to 30 observations), a t-statistic of ≈1.75 will yield similar probabilities. A large t-statistic indicates that the error found is real (not random) and ensures the validity of comparisons between varying sample sizes.